



# **Airborne monitoring of Harmful Algal Blooms over Lake Erie**

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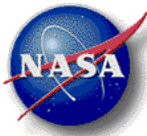
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# Airborne HSI Research Activities



- Great Lakes
  - Harmful Algal Blooms (NOAA)
  - Invasive plant species in wetlands (EMU)
- Cropland data obtained for University of Toledo / OhioView

# Importance of Monitoring Great Lakes Harmful Algal Blooms (HABs)



- In the Great Lakes an example is a *Microcystis* bloom which has reoccurred in western Lake Erie, Saginaw Bay and Lake Ontario since at least 1995
  - Cause is still being investigated, leading theories are increase in nutrient loading and ecological change from invasive species
  - *Microcystis* may contain a toxin, Microcystin, which can be harmful to humans, fish, and wildlife
  - Multiple blooms have occurred since 1995 where the *Microcystis* concentration was significantly higher than the WHO recommendations for drinking water
- Goal is to develop remote sensing capability to detect the pigment Phycocyanin, an indicator of *Microcystis*, in low concentration as an early indicator of bloom prediction



# Lake Erie Algal Bloom September 2007



# How aerial monitoring fits with other measurement capabilities



- In Situ – many physical measurements at a point but poor spatial coverage
- Satellite – Measurements over a large area but poor / marginal temporal coverage
- Aerial Monitoring is Complementary
  - More frequent measurement opportunities to understand rapidly changing blooms
  - Lower concentrations potentially detectable because of higher spatial and spectral resolution
  - Can quickly locate areas of interest and guide in situ measurements
  - Easily tailor instrumentation to suit the problem

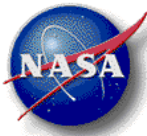
Observation Method	Observation Frequency	Resolution
Satellite Landsat TM	Once every 8 days	30 meter
Satellite MODIS	2/day	1km
Satellite MERIS	Every 2-3 days	300m
Satellite SeaWiFS	1/day	1km
Research Vessel In situ	Flexible	Point
Aerial Monitoring	As Needed	1- 5 m (Variable)



# Operations

## Algal Bloom Formation – Western Lake Erie

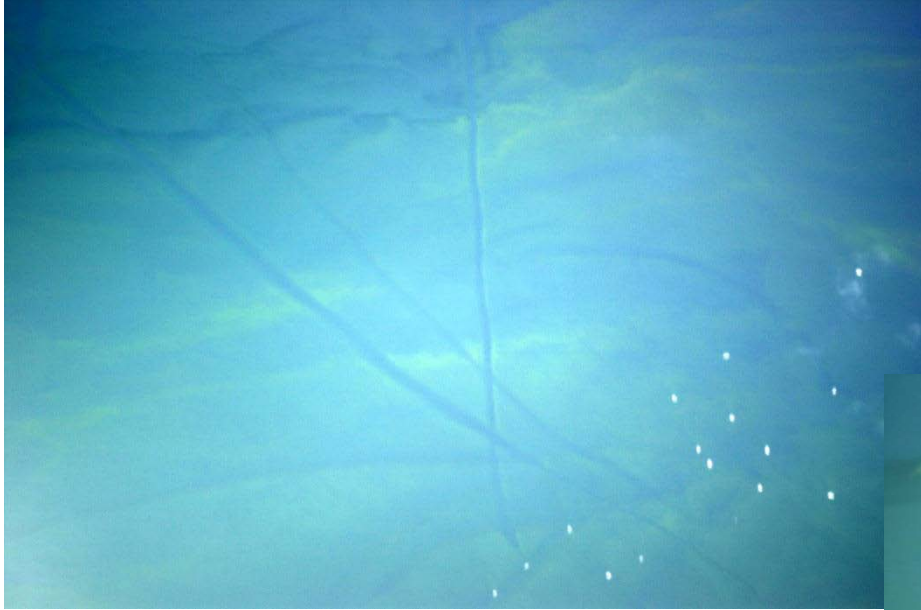
### September 1



Algal bloom is visible in Lake Erie Western Basin near the Bass Islands. The bloom is very cohesive and does not seem to mix with the sediment well.



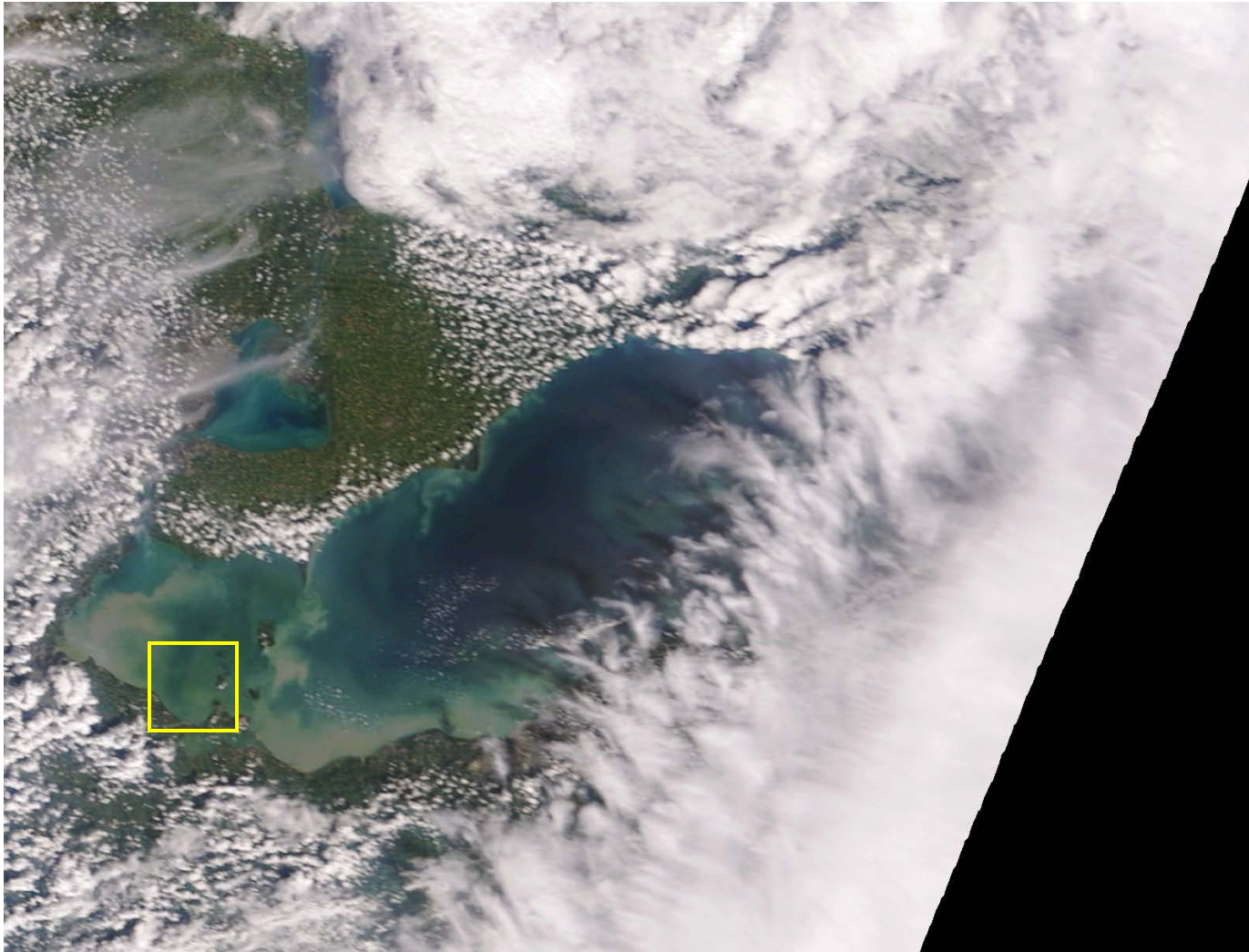
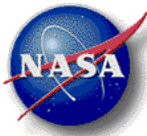
# Algal bloom visible on surface Western Lake Erie September 5, 2006



On this day the bloom has developed so that mats are visible on the surface and tracks can be seen from boats traveling through the algae

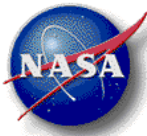


# Image of Lake Erie from Terra on Sept. 5





# Comparison of MODIS image from Terra satellite (background) with Hyperspectral Image (inset) both taken on Sept. 5

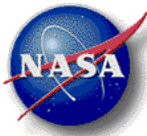


# Brief History of NOAA / NASA Collaboration in Hyperspectral Imaging



- In 2006 Developed Generation I miniature Hyperspectral Imager (HSI). Weighed less than 4 kg and size was about 11 cm x 16 cm x 3 cm
- Acquired HSI data of Algal blooms in Lake Erie and Grand River sediment plume in Lake Michigan with concurrent water sampling conducted by GLERL and others (2006)
- In 2007 Developed 2<sup>nd</sup> generation Hyperspectral Imager suite that is about twice the size of the Gen I instrument
- Acquired HSI data of Algal blooms in Lake Erie and Saginaw bay with concurrent water sampling conducted by GLERL and others. (2007)
- Specifically designed for remote sensing water quality application (low reflectivity ~ 6% max)
- In 2009 acquired concurrent water samples and over-flight of 75 data points

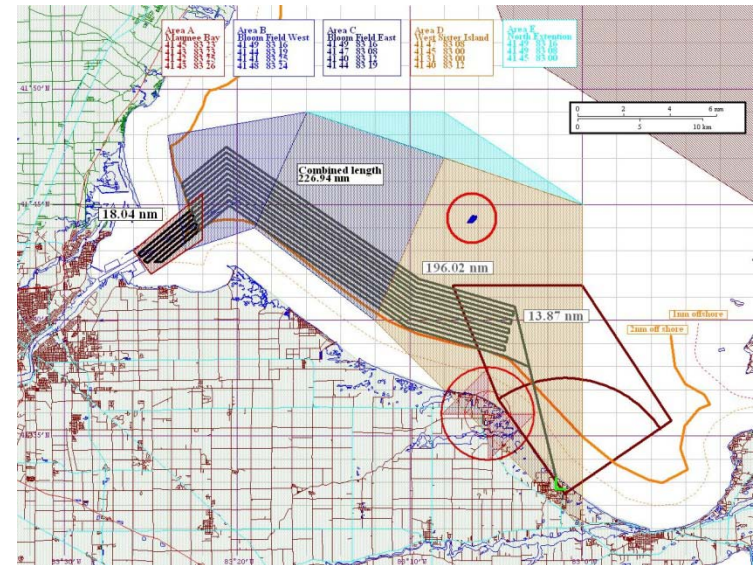
# Original Plan for 2006



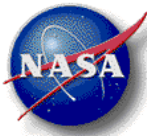
- **Develop Suite of instruments for UAV**
- **(In 8 months!!)**
  - Hyperspectral Imager (405 – 867 nm spectral range and 2 nm spectral resolution)
  - Point Spectrometer
  - Attitude sensors
  - GPS receiver
  - **Payload Volume**: 125 mm x 150 mm x 175 mm
  - **Weight** < 3 kg total system mass,
  - **Power** < 35 W



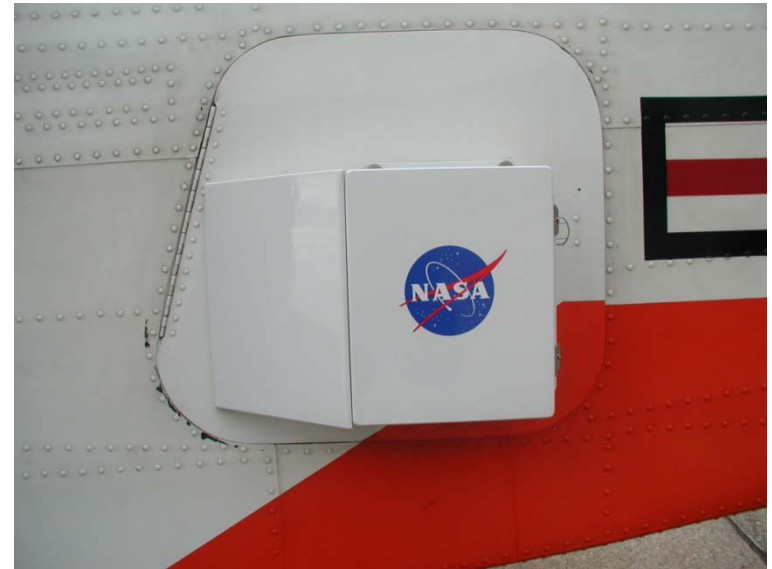
- **NOAA provided *Microcystis* recognition algorithm**
- **Utilize Low cost UAV platform (Aerosonde)**
  - Wallops partnership
  - Rapid on-demand Response
  - Able to operate below cloud cover
  - Potential for low cost operation
  - Instrumentation can be customized
  - Autonomous or teleoperated



# Hyperspectral Imager Mounted to T-34



All 2006 Great Lakes  
operations carried out on T-34





# HSI Specifications



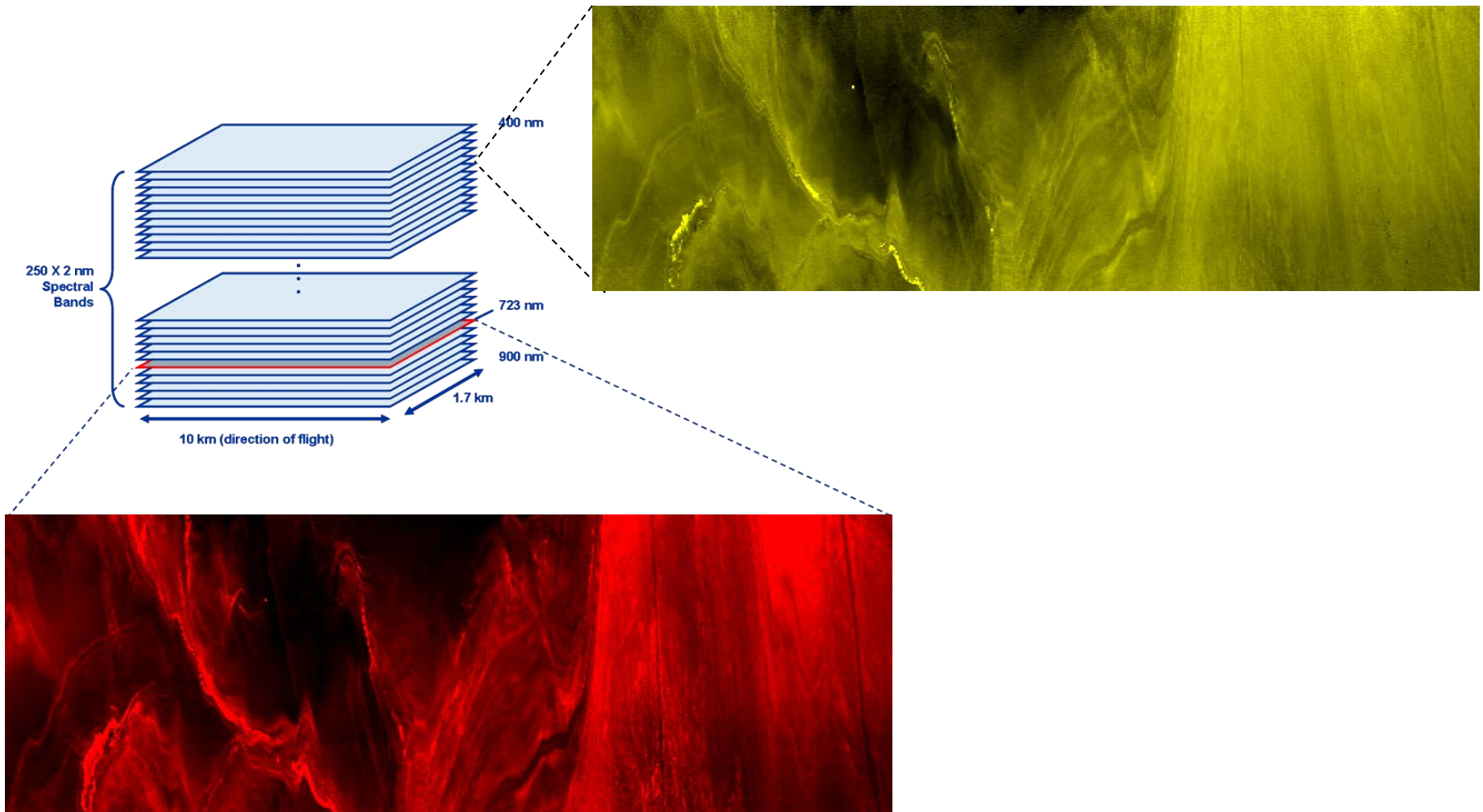
**GEN I HSI**



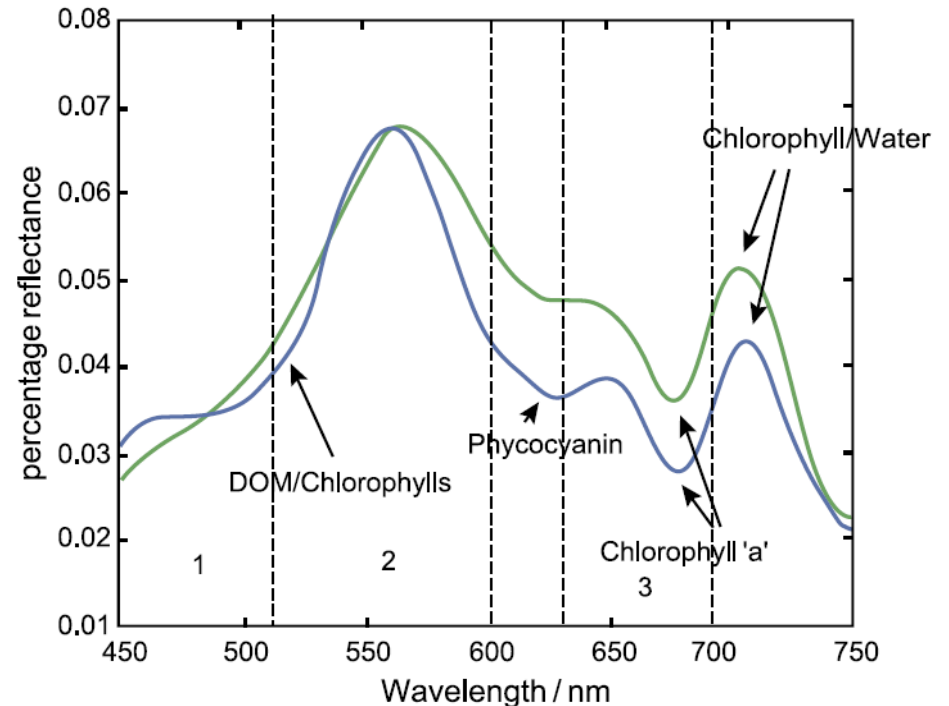
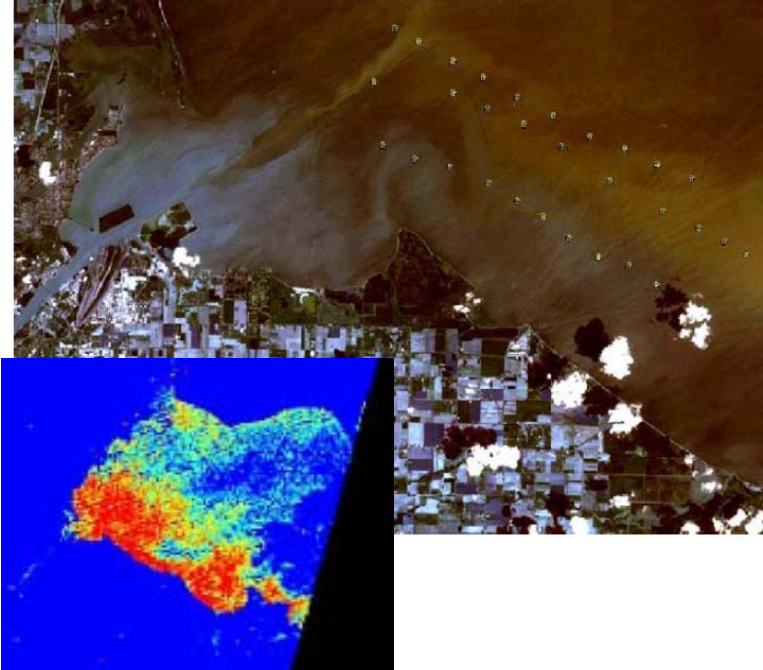
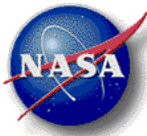
**GEN II HSI**

- GEN I hyperspectral imager built in **2006** and field tested in **2006** and **2007**
- GEN II hyperspectral imager built and field tested in **2007** and **2008**
- **Gen II Specifications**
  - Push Broom Hyperspectral Imager
  - Modular design for fast turnaround reconfiguration
  - Optionally configured with scan capability for operation from stationary platform
  - SNR: >800
  - FOV: 16 degrees
  - Optical Spectral Resolution: 2.5 nm
  - Sampling Resolution: 1 nm
  - Frame Rate: 30 fps
  - Spectral Range: 400 – 900 nm
  - Power: 30 watts
  - Weight: 6 kg (Imager and CPU)

# Hyperspectral Imaging Data



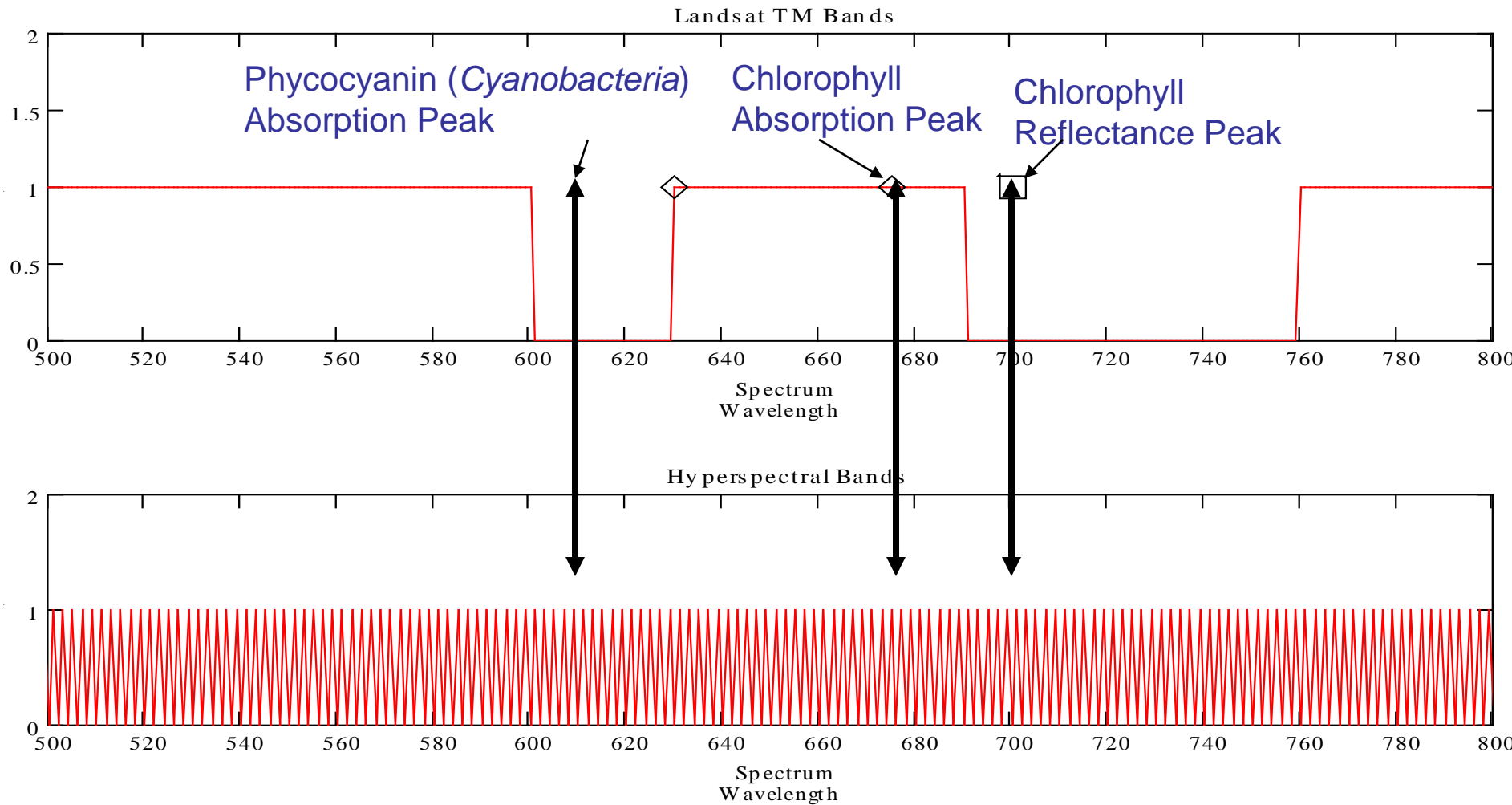
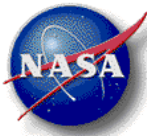
# Detecting Blue Green Algae from LANDSAT TM



R. K. Vincent et al., *Remote Sensing of Environment*, **89** (2004) 381-392.

- Experiment conducted by Researchers at University of Toledo and Bowling Green State University, July 2000

# Comparing LANDSAT TM data to Hyperspectral data





# Atmospheric Effects

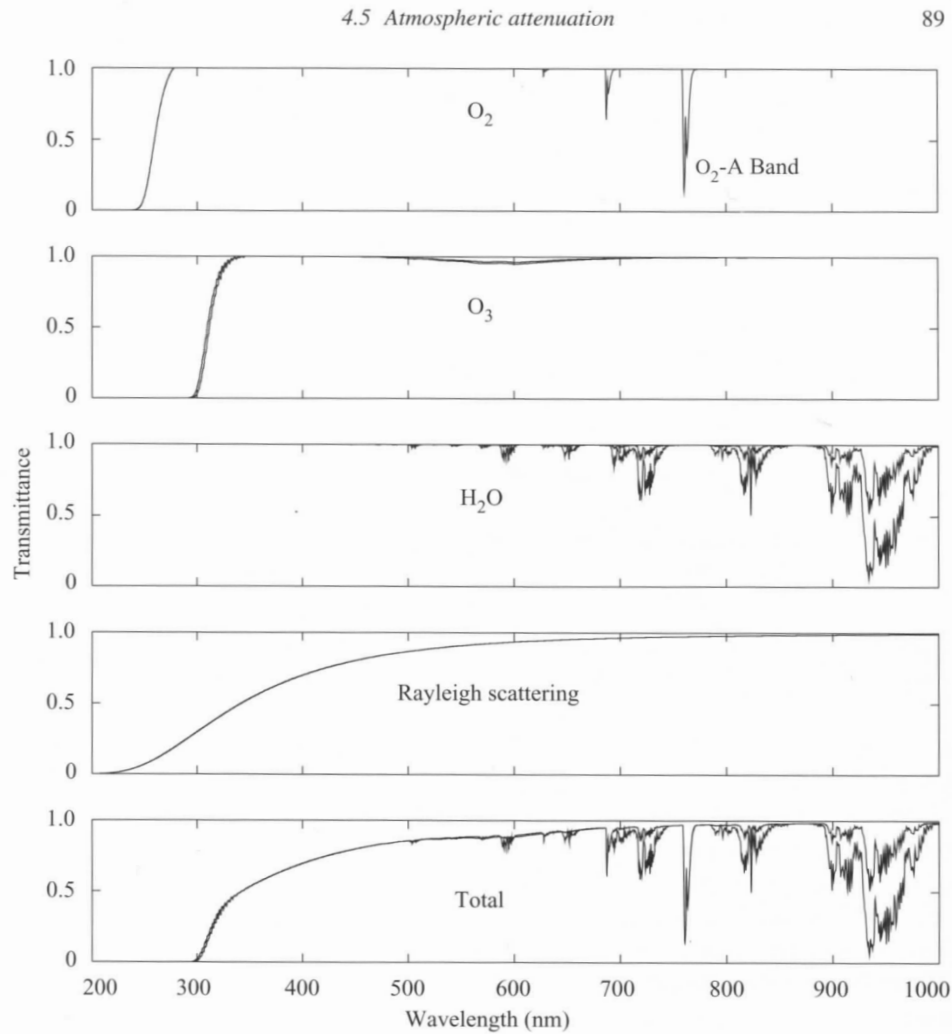
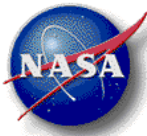
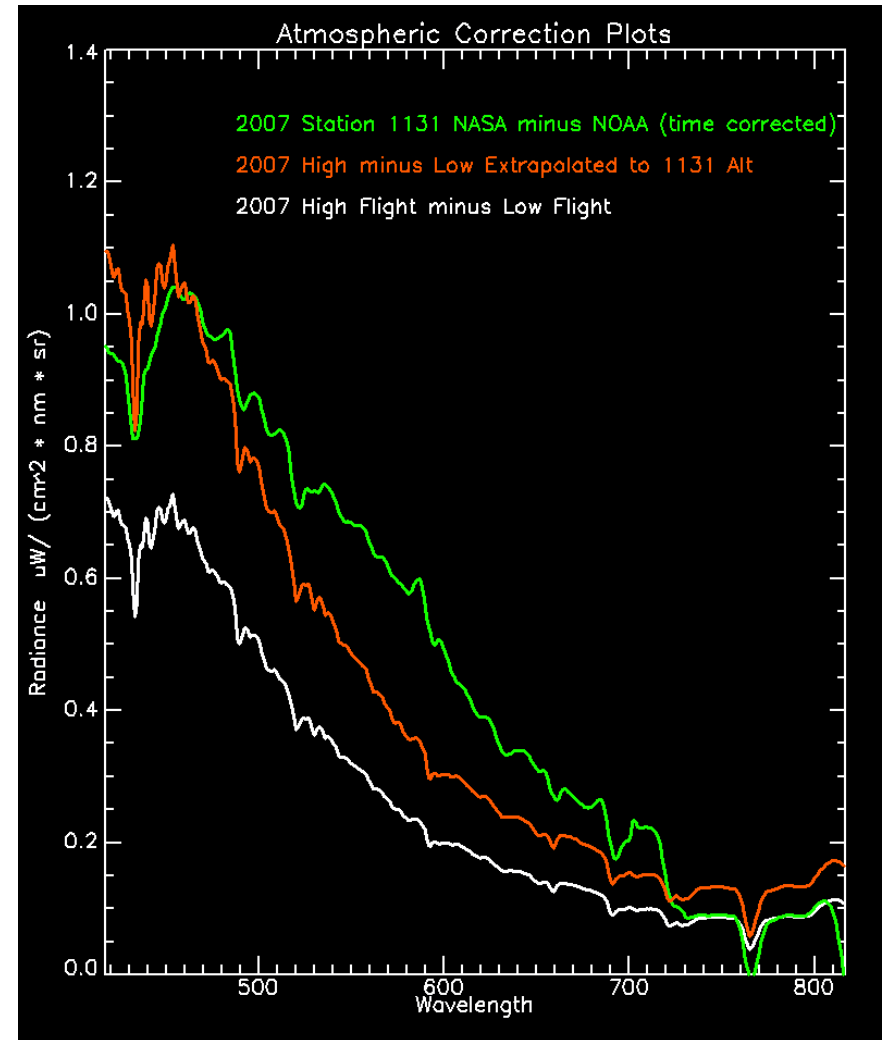
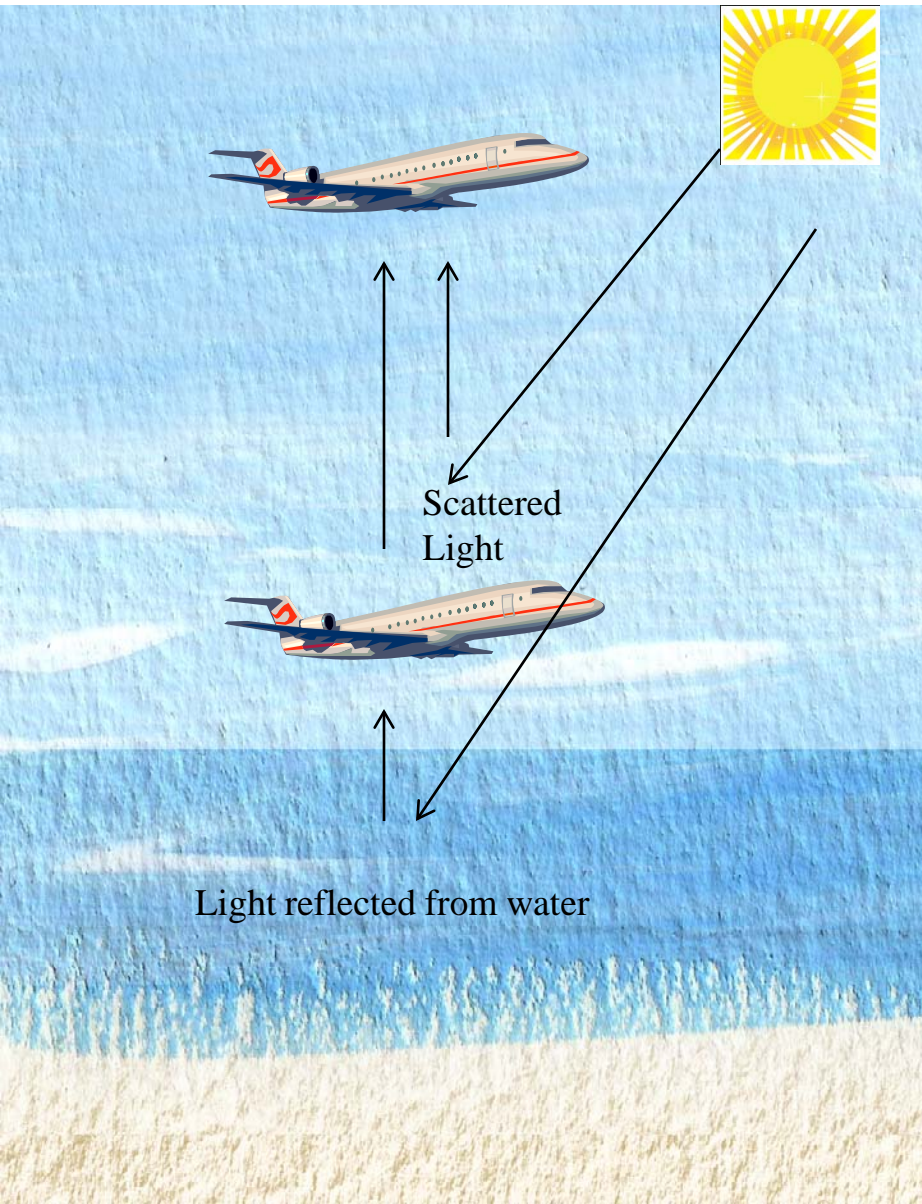


Figure 4.10. The wavelength dependence of the atmospheric transmittance for oxygen, ozone, water vapor, and Rayleigh scattering, for the two extreme MODTRAN cases of Tropical and Sub-arctic winter. For water vapor, the lower curve corresponds to the winter case.

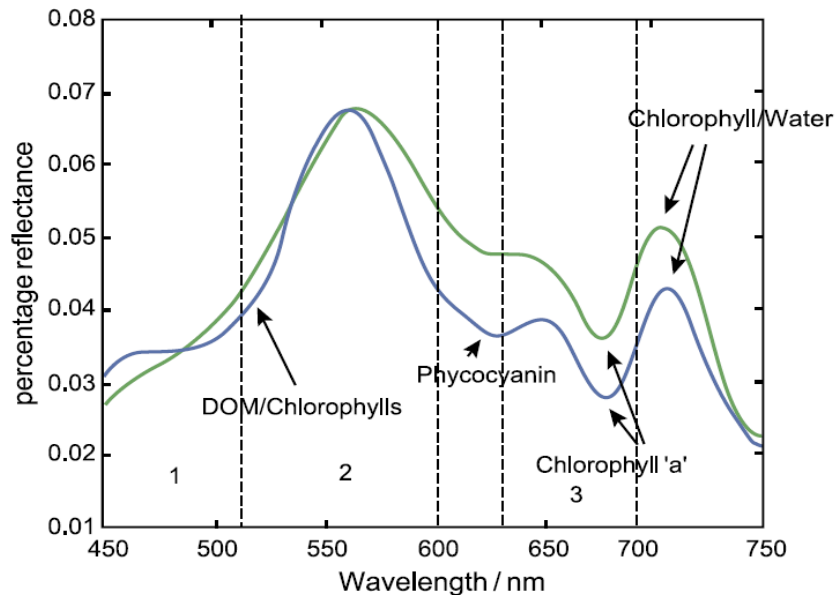
# Atmospheric correction

## Using High – Low overpass of clear water

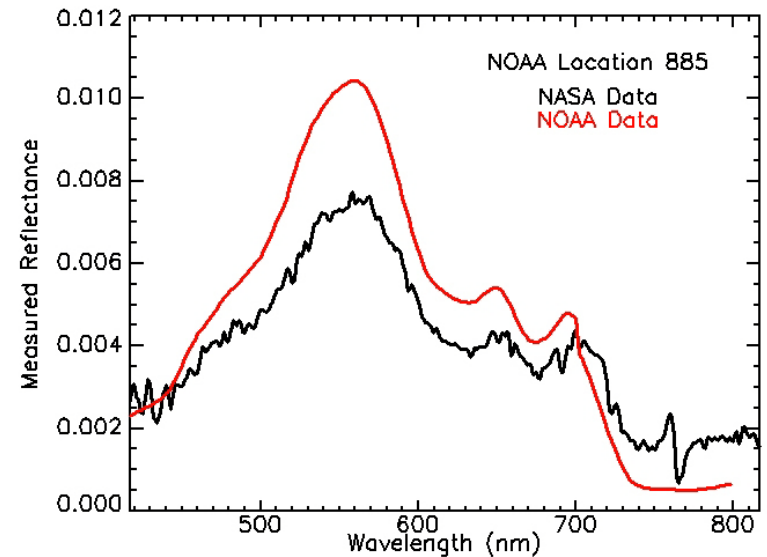
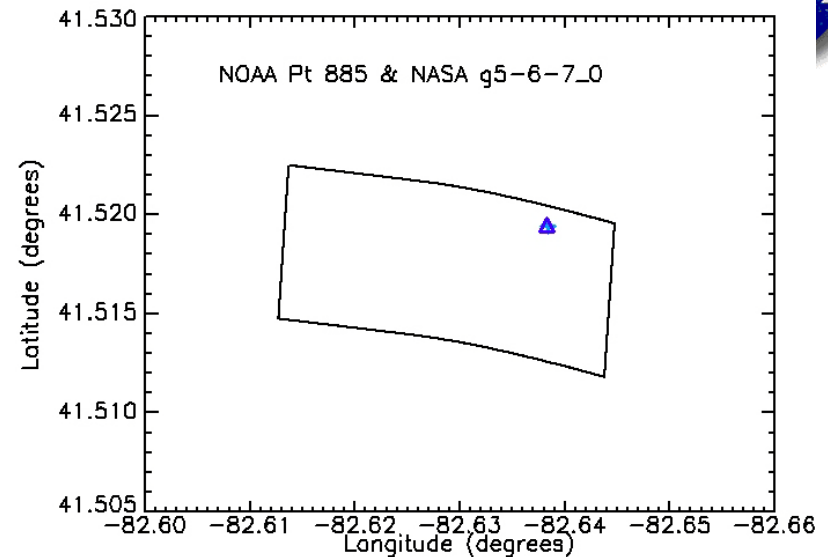


# Point 885

- Overflight Sept. 13, 2007
- Surface measurement Sept. 14, 2007
- Good correlation with phycocyanin
- Phycocyanin concentration  $153.9 \mu\text{g/l}$
- Microcystin concentration  $0.526 \mu\text{g/l}$

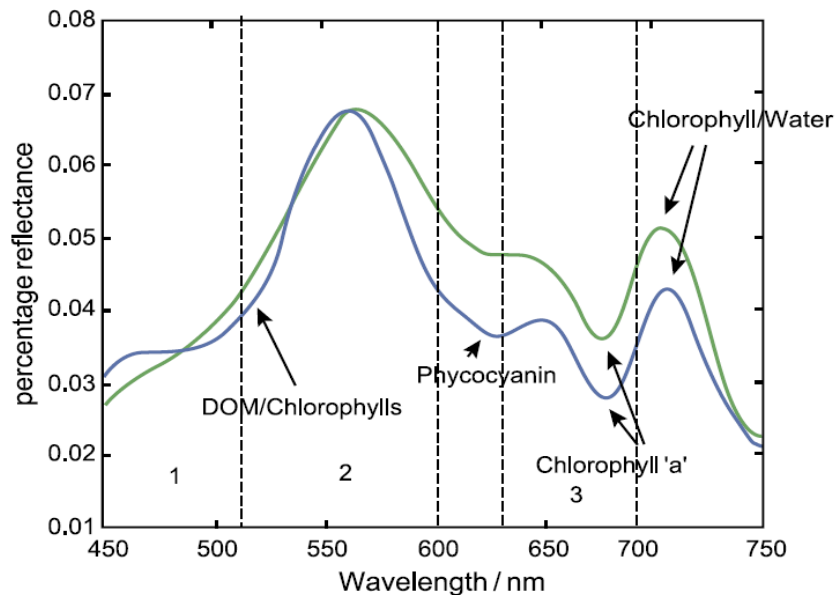


R. K. Vincent et al., *Remote Sensing of Environment*, **89** (2004) 381-392.

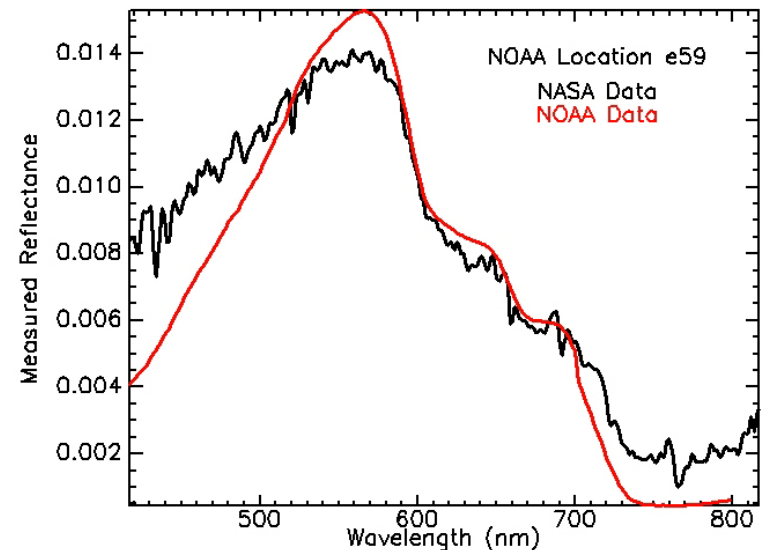
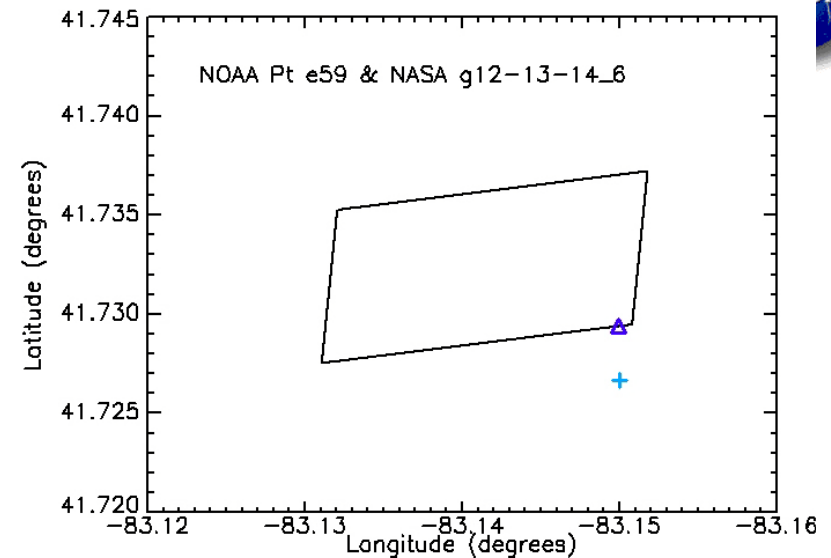


# Point e59

- Overflight Sept. 13, 2007
- Surface measurement Sept. 13, 2007
- Good correlation with Chlorophyll
- Phycocyanin concentration  $1.43 \mu\text{g/l}$
- Microcystin concentration  $0.011 \mu\text{g/l}$

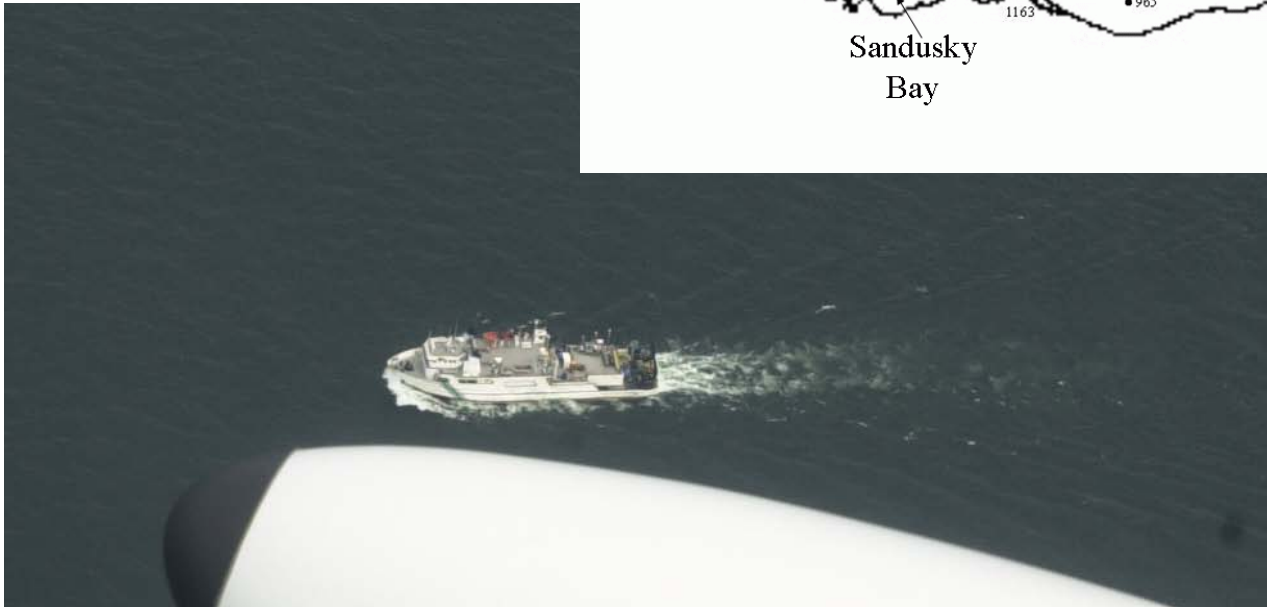
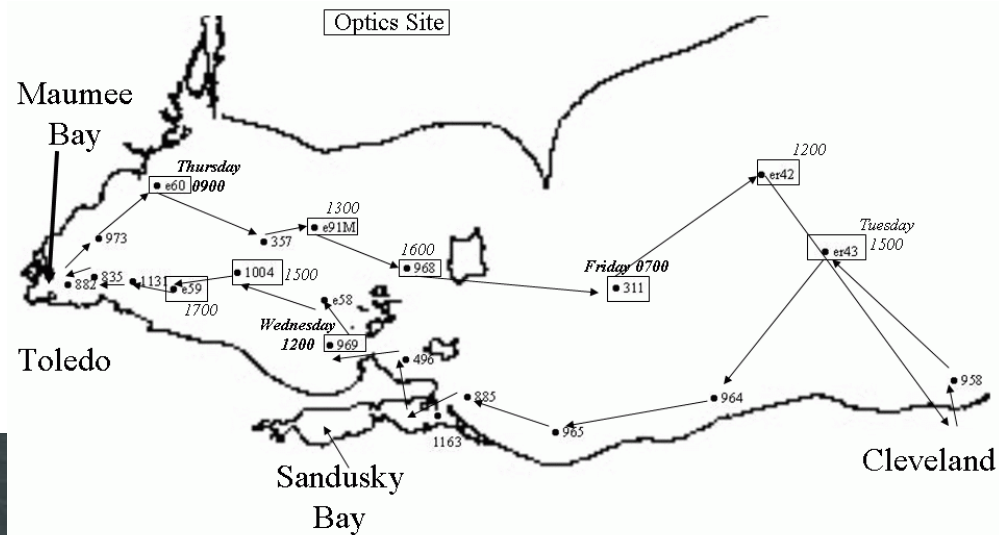


R. K. Vincent et al., *Remote Sensing of Environment*, **89** (2004) 381-392.





# HSI Data Acquisition Occurred at the same time as the EPA R/V Lake Guardian Cruise – Sept 12<sup>th</sup> Thru 14<sup>th</sup>

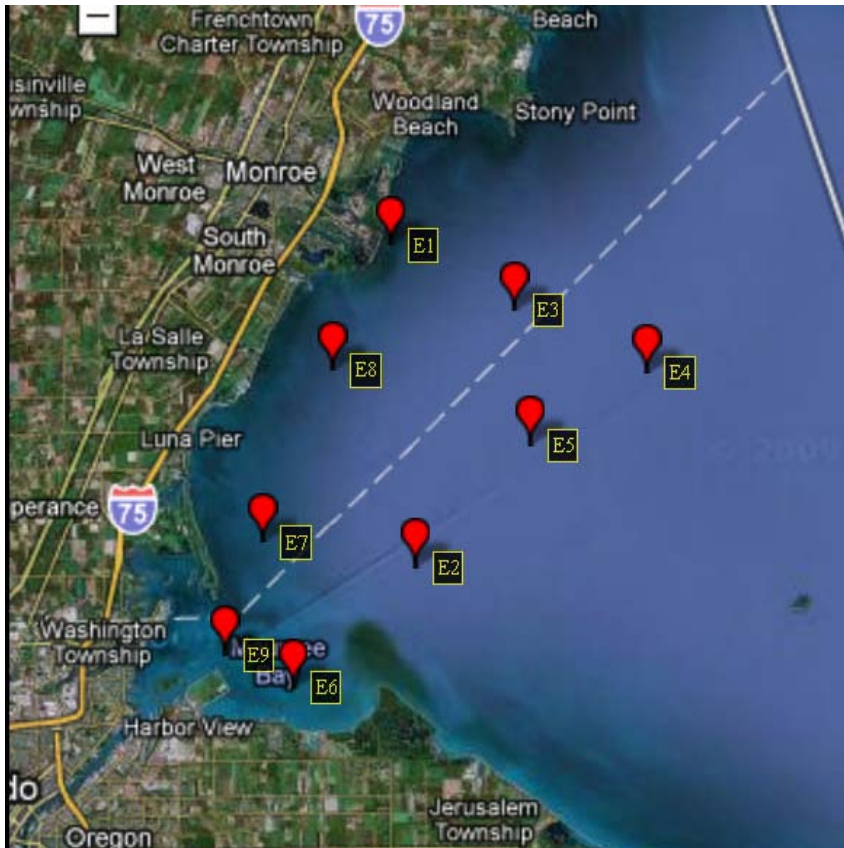
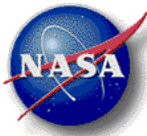


# Water Sampling



- Water Sampling conducted from both EPA RV Lake Guardian as well as NOAA boat
- Two Samples taken at each location
- Each sample location was imaged from the aircraft during the same day.
- Percent Variability of measured Phycocyanin concentration between the two samples averaged 36%

# Western Lake Erie Sampling Points



- Concurrent water sample and overflight dates in 2009

August 11

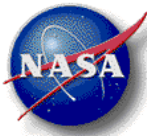
August 25

September 1

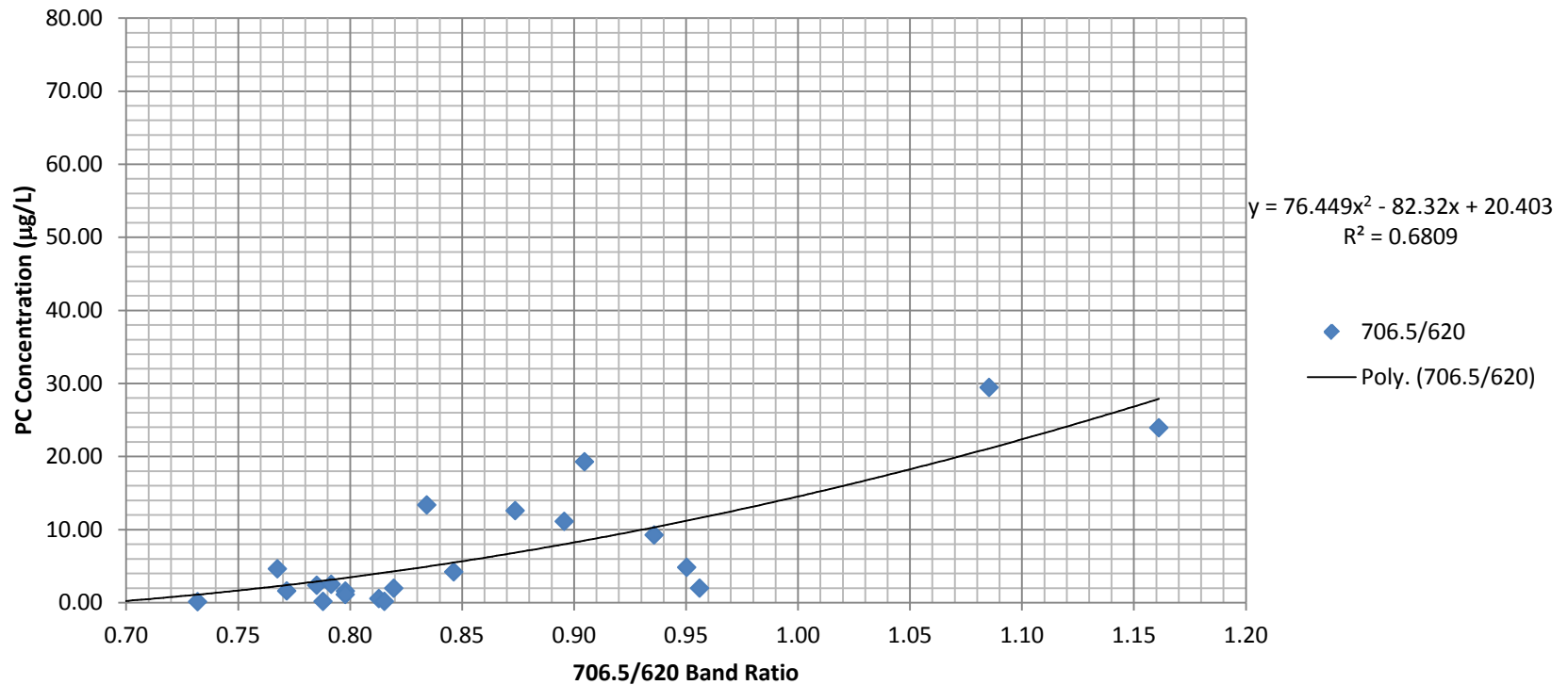
September 14

October 1

# Band Ratio correlation to PC concentration



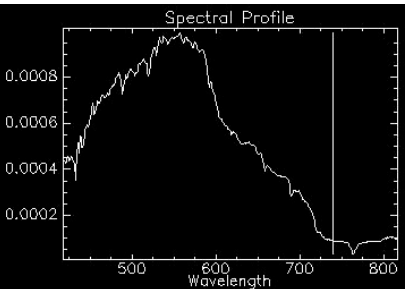
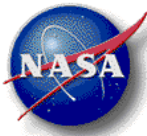
## 706.5/620 ratio



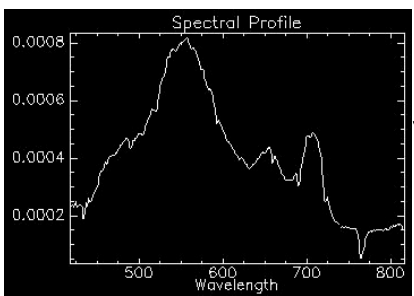
Simis, et al. (2005)



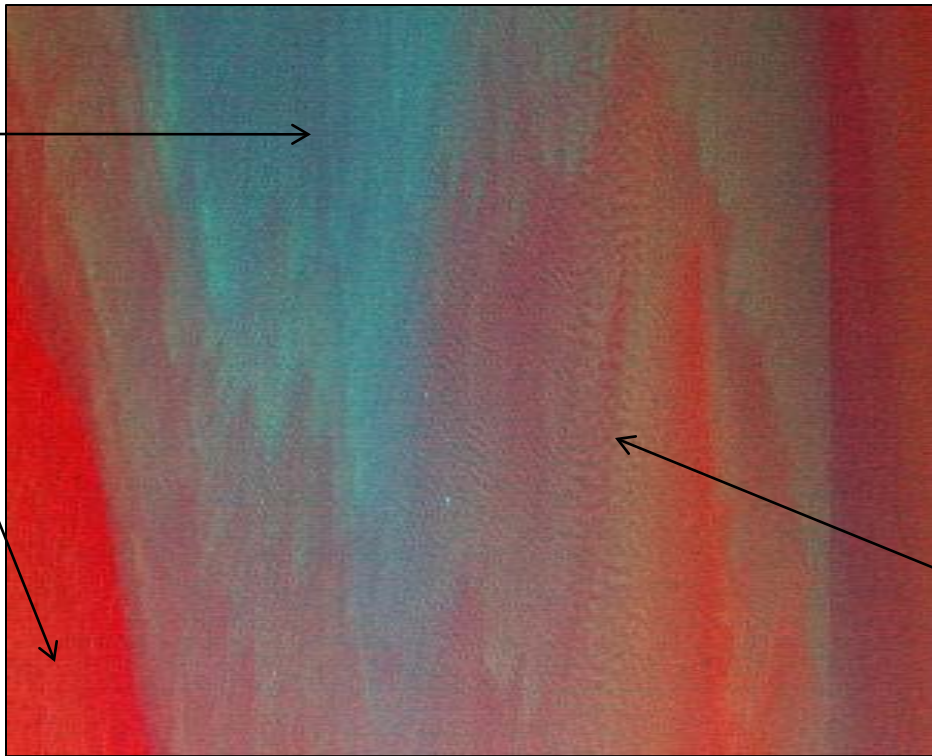
# Microcystis Indication Map



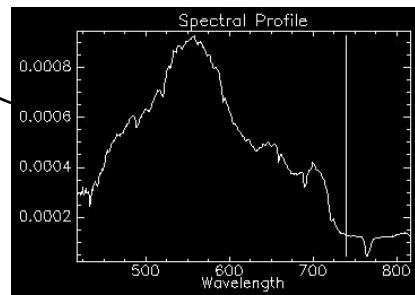
Sediment Spectrum



Microcystis Spectrum



0.8 km



Mixed Spectrum

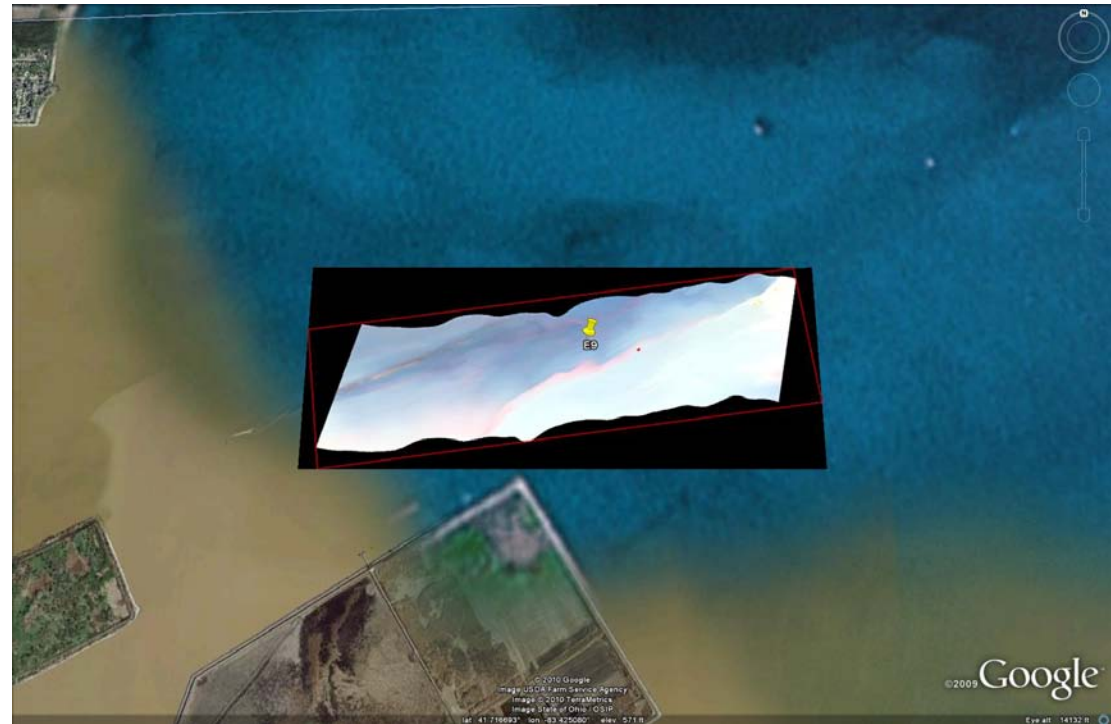
1.4 km

Stronger indication of Microcystis in red

# Spatial Variability in PC concentration



- Note that there are ribbons of very high concentration within 100 meters of sample location
- Repeat water samples from this location varied by 36%
- Both HSI data and repeat sample variability suggest that the sample point is in an area with strong concentration gradient

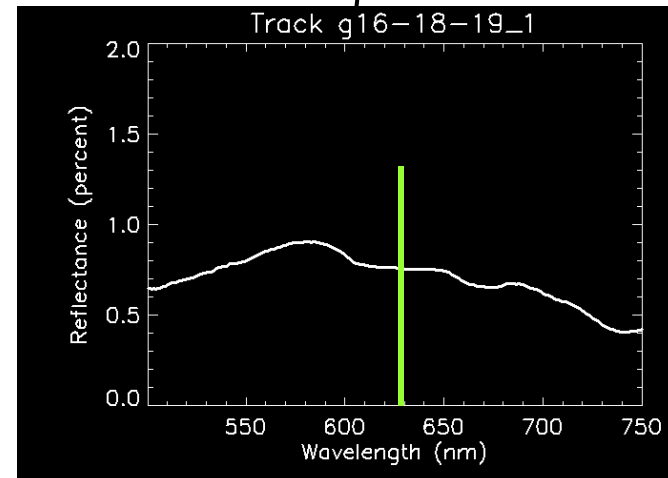
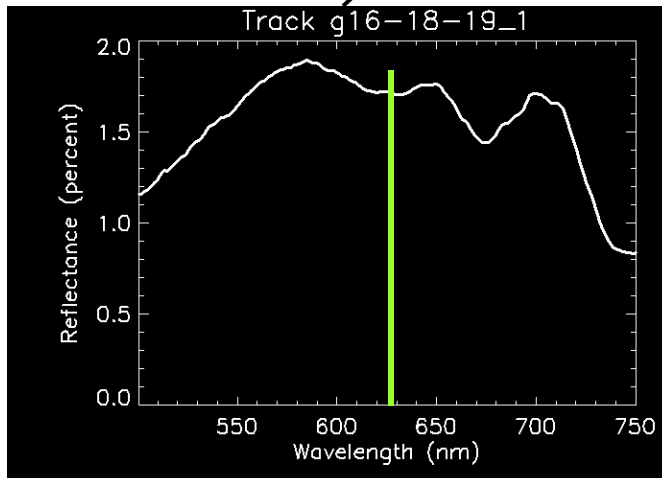
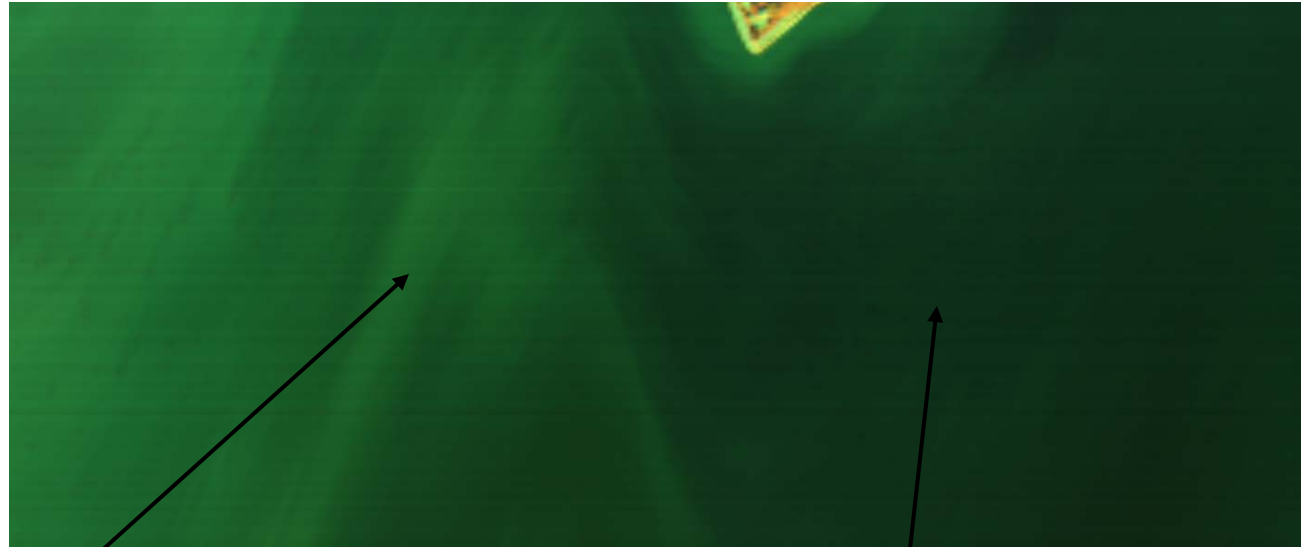


- Sample location is shown by pushpin
- Higher indication of microcystis is indicated by red coloring

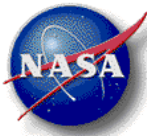
# Lake Erie HSI – Maumee Bay September 13, 2007

Slight indication  
of Phycocyanin in  
bay (left)

No indication  
further out (right)



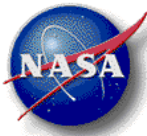
# Summary HAB research



- Two generations of Hyperspectral Imagers have been built and flight tested the past four years
- Data has been acquired in 2006, 2007 and 2009 with concurrent water sampling
- Concurrent surface reflectance measurements match well with airborne reflectance measurements
- Preliminary results show that a band ratio technique typically used for remote measurement of Chl a had best correlation to phycocyanin concentration
- Presently analyzing data for seasonal variation

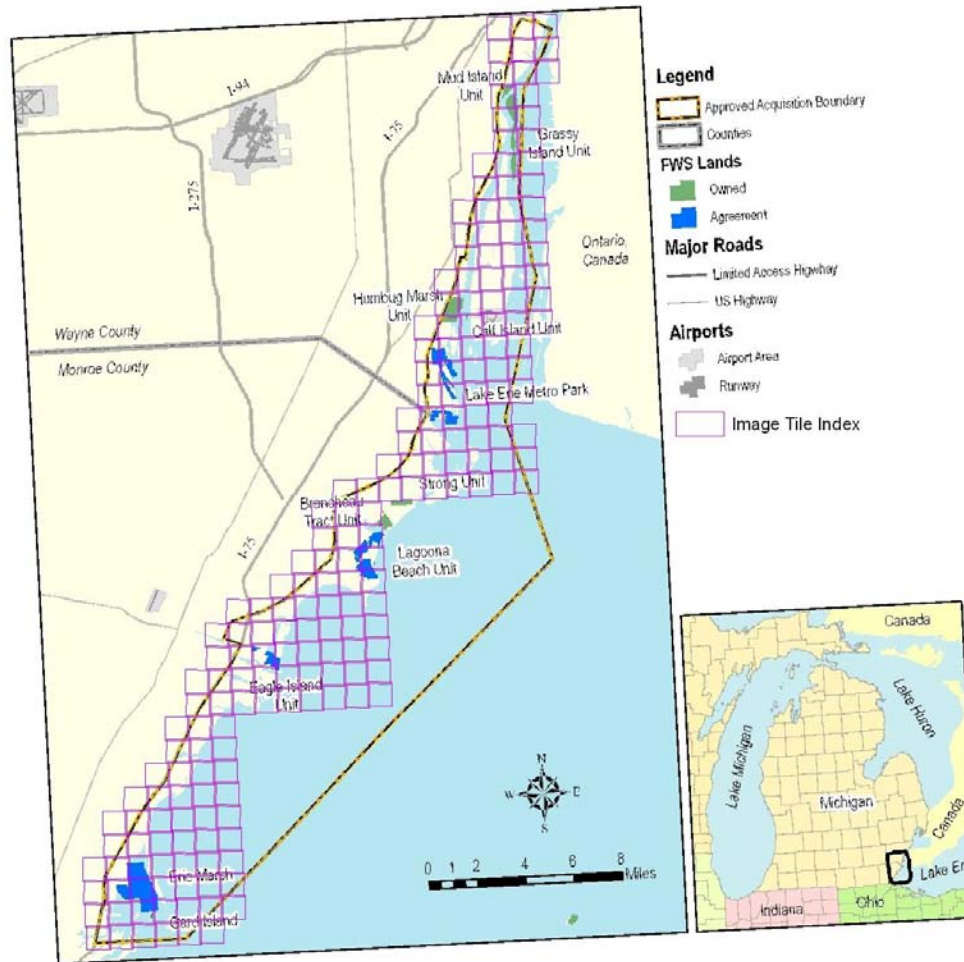


# Studying Detroit River International Wildlife Refuge

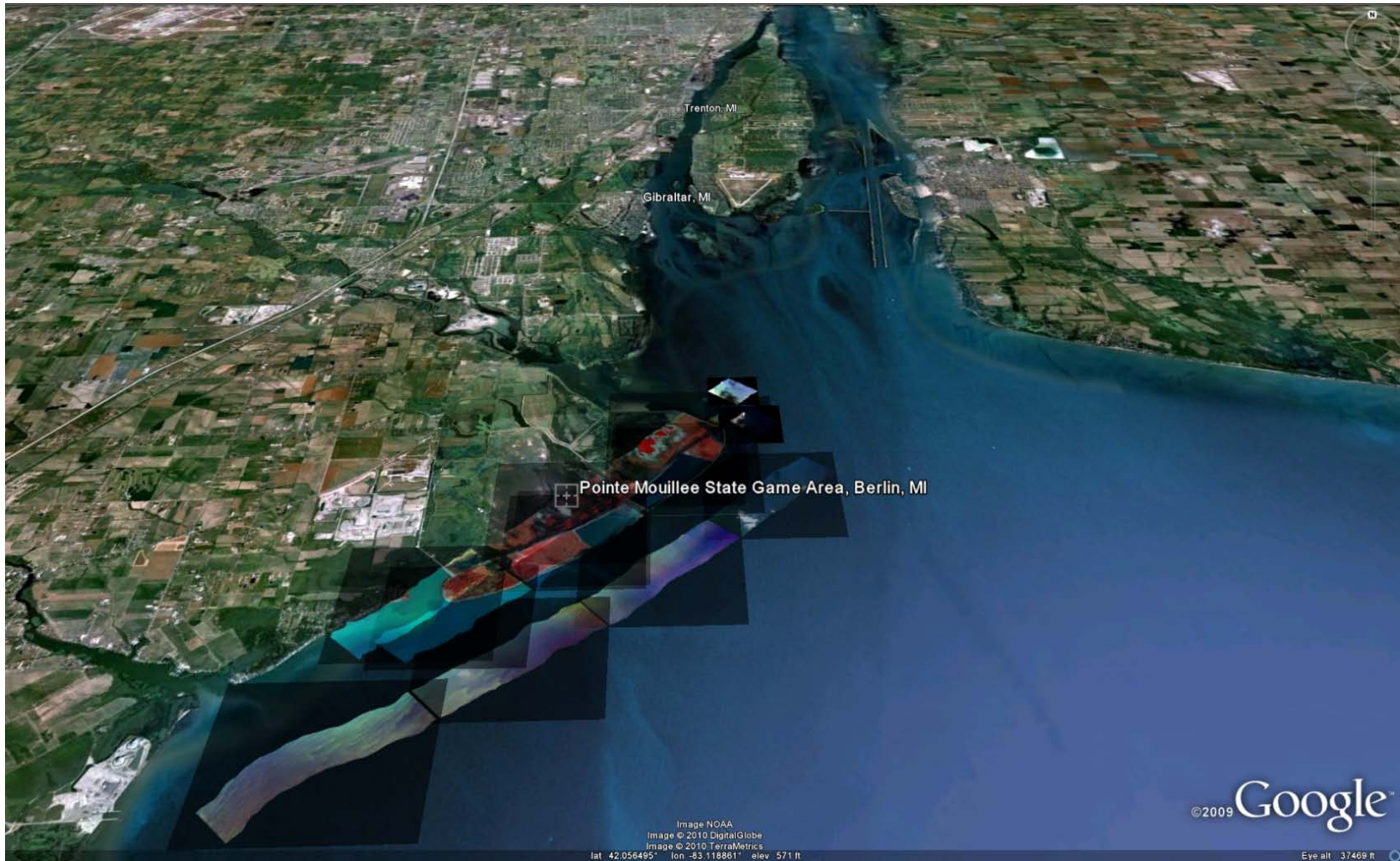
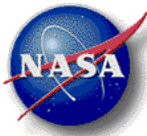


- NASA GRC and Eastern Michigan University are utilizing an airborne hyperspectral imager to map invasive plant species in the Detroit River International Wildlife Refuge.
- The spread of invasive species is a global problem with significant negative economic and environmental impacts. In the Great Lakes region, invasive species in wetland ecosystems are of particular concern, because coastal wetlands support a number of critical ecosystem services, including wildlife and waterfowl habitat, water-quality improvement, and carbon sequestration.
- These ecosystem services are currently threatened by the aggressive spread of invasive wetland plants such as the common reed, *Phragmites australis*, reed canary grass, *Phalaris canariensis*, purple loosestrife, *Lythrum salicaria*, and the aquatic alga, *Lyngbya wollei*. Currently, a major focus of management efforts in coastal Great Lakes wetlands is on *Phragmites*, which forms dense stands, altering wetland ecosystems through a number of potential pathways.
- Scientists at Eastern Michigan University are developing remote sensing techniques to determine the extent of *Phragmites* throughout the Detroit River International Wildlife Refuge (DRIWR) and track its progress.
- Concurrent field data for ground reference, calibration and validation of image processing, will be conducted.

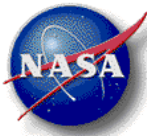
# Detroit River International Wildlife Refuge



# Study Plant invasive species in Lake Erie protected wetlands in cooperation with EMU



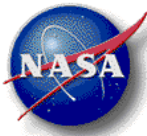
# Status



- 445 Gb of HSI data obtained in 2010
- Data has been geo located and the radiometric correction has been completed
- Processed data has been delivered to collaborators at EMU and they are presently analyzing the data



# HSI Operational Summary



- Great Lakes 2006, 2007, 2009
- Lake Erie Wetlands 2010
- Presently upgrading capability for next deployment in 2013

# Acknowledgements



We wish to thank Juli Dyble for collecting water samples and especially Greg Boyer and his PhD student for processing the water samples for phycocyanin concentration.